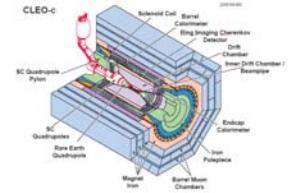


PANIC05, Santa Fe, NM

Oct 24 - 28, 2005



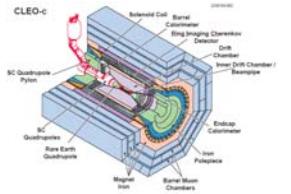
Recent $\psi(2S)$ and J/ψ results from CLEO

GuangShun Huang

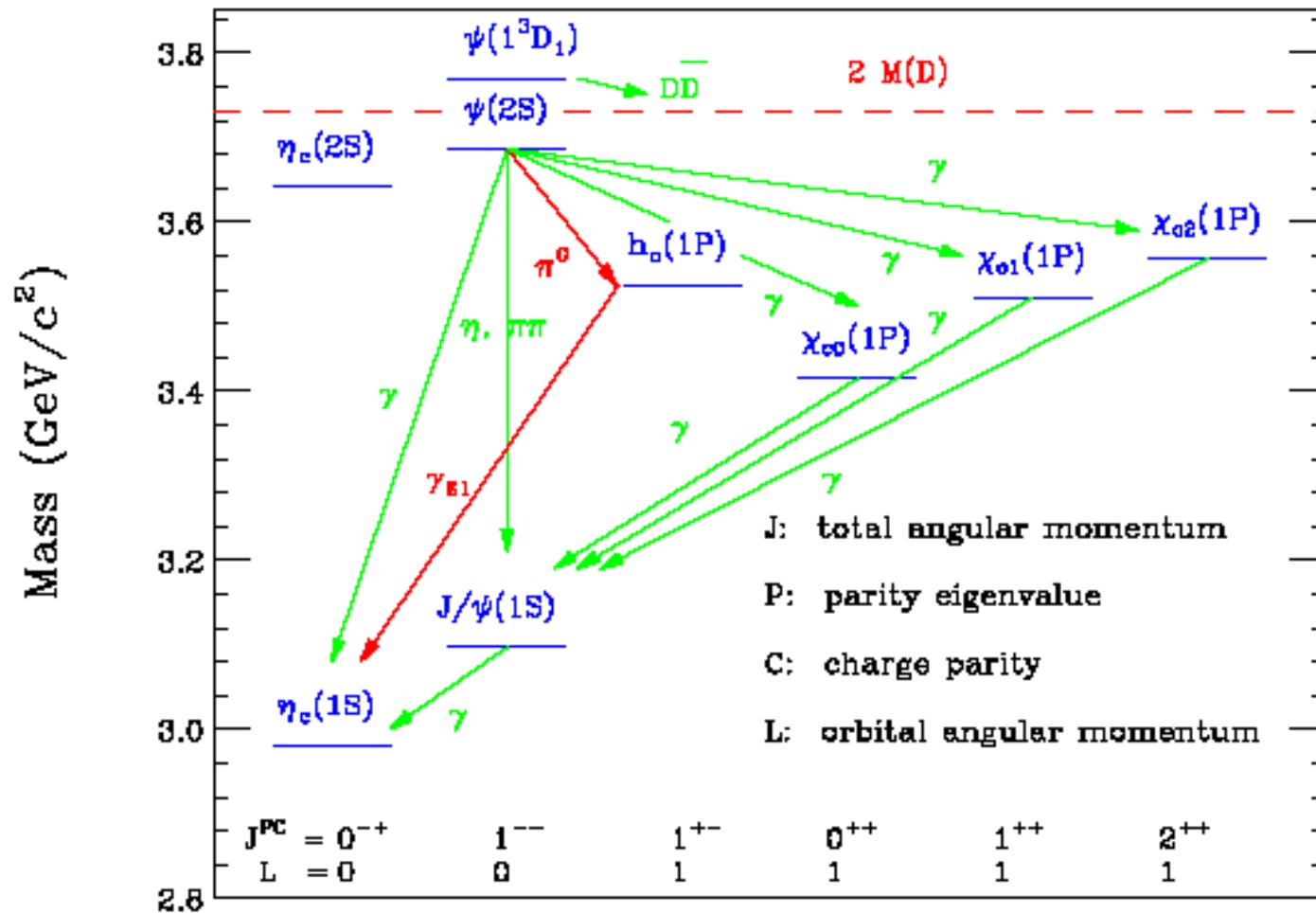
Purdue University

(Representing the CLEO collaboration)

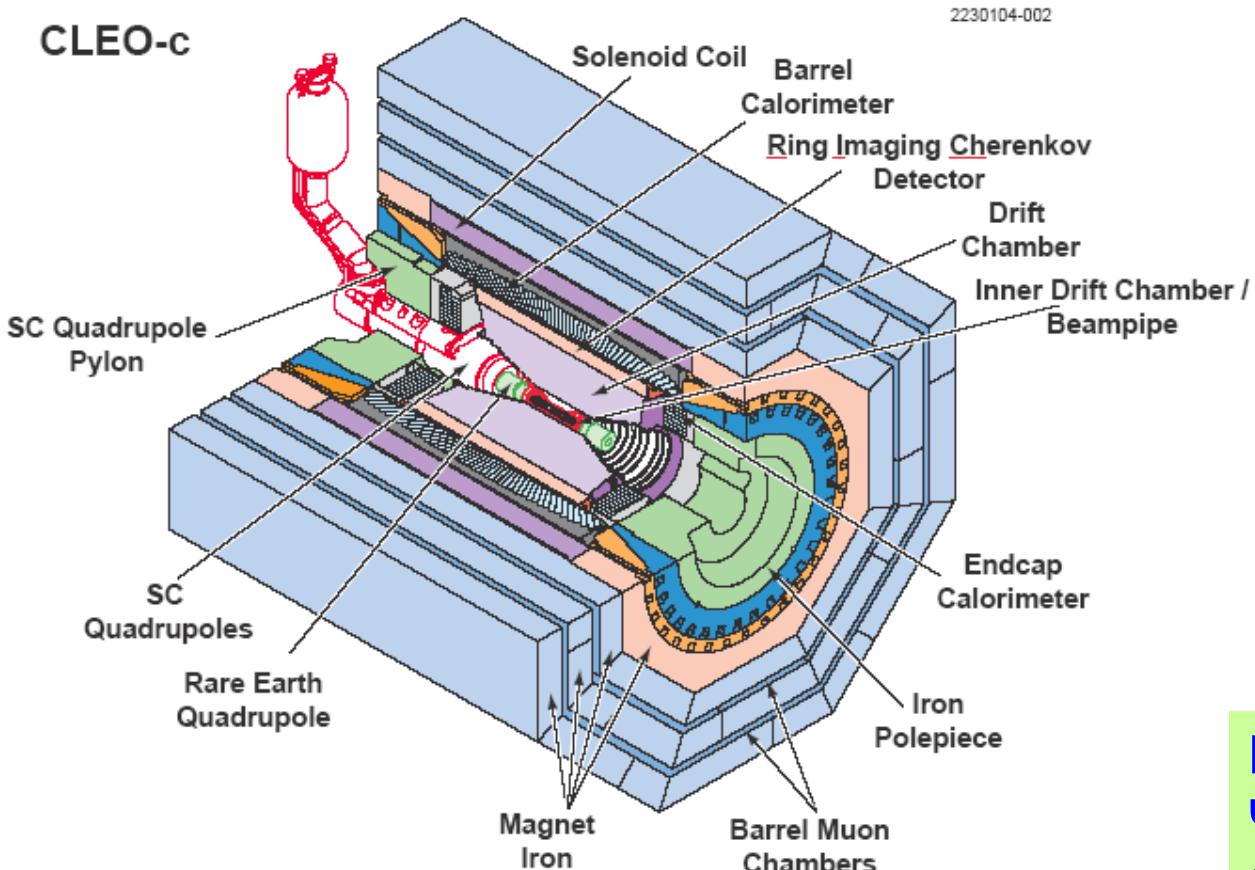
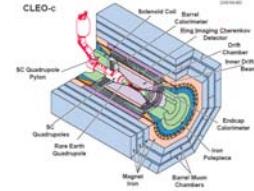
- $\Psi(2S) \rightarrow X J/\psi$
- $J/\psi \rightarrow \ell^+ \ell^-$
- $\Psi(2S) \rightarrow \text{baryon pair}$
- $\Psi(2S) \rightarrow \text{multi-body hadrons}$
- $\Psi(2S) \rightarrow K_S K_L$



Charmonium

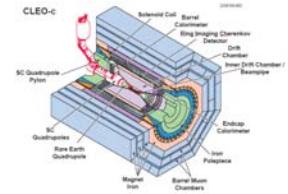


CLEO-c detector



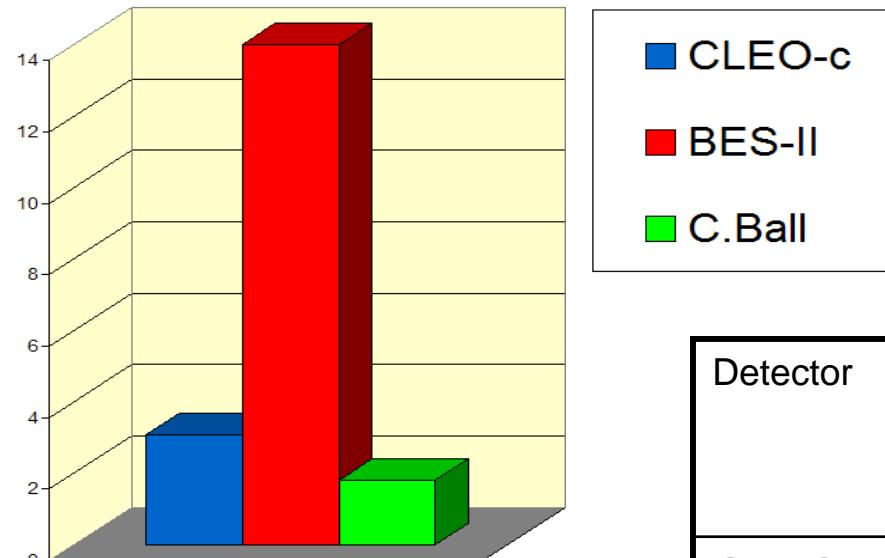
B=1 Tesla
0.6% p @ 1GeV/c
2.2% E γ @ 1 GeV
5% E γ @100 MeV
Track 93% of 4π
RICH 80% of 4π

Data sets:
 $\Psi(2S)$ (3686) 5.63pb^{-1}
Cont. (3670) 20.70pb^{-1}



CLEO vs other experiments

$\Psi(2S)$ in millions of resonance decays

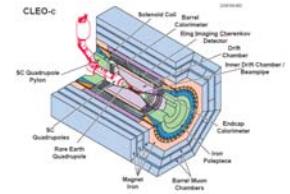


Detector	Magnetic field	σ_p/p resolution at $p=1$ GeV
CLEO-c	1.0T	0.5%
BES-II	0.4T	2.4%
C.Ball	0	--

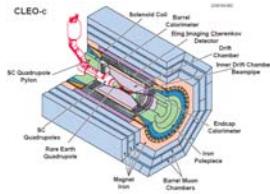
Detector	Calorimeter crystals	$\sigma_{E\gamma}$ resolution at $E\gamma=100$ MeV	Number of inner segments (crystals)	Inner radius (cm)
CLEO-c	CsI(Tl)	4.8 MeV	7800	100
C.Ball	Nal(Tl)	4.8 MeV	672	25
BES-II	Sampling	70 MeV		

CLEO-c $\Psi(2S)$ data sample is not the biggest in the world, but the detector is excellent (both tracking **and** γ detection), and we also have a large continuum data sample.

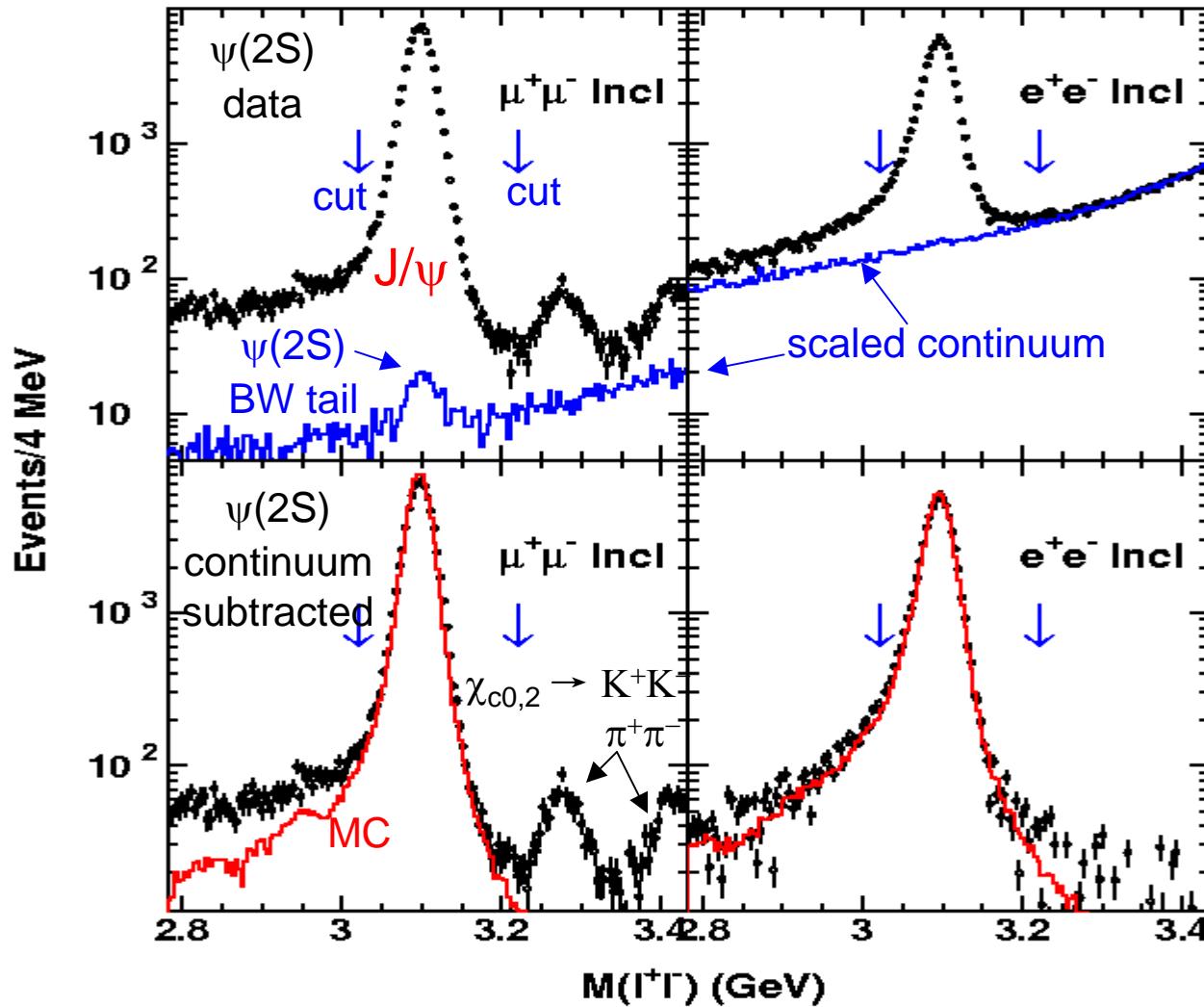
$\psi(2S) \rightarrow X J/\psi(1S)$



- Hadronic transitions ($X = \pi\pi, \eta, \pi^0$):
 - $\text{BR}(\psi(2S) \rightarrow X J/\psi(1S))$ needed in phenomenological models;
 - $\text{BR}(\psi(2S) \rightarrow \pi^+ \pi^- J/\psi(1S))$ often used as normalization;
 - $\text{BR}(\psi(2S) \rightarrow \pi^0 J/\psi(1S)) / \text{BR}(\psi(2S) \rightarrow \eta J/\psi(1S))$ is sensitive to $m_u - m_d$ (isospin violation)
 - Previous ratio of $\text{BR}(\psi(2S) \rightarrow \pi^0 \pi^0 J/\psi(1S)) / \text{BR}(\psi(2S) \rightarrow \pi^+ \pi^- J/\psi(1S))$ at odds with isospin symmetry (beyond amount of expected violation)
- Photon cascades $\psi(2S) \rightarrow \gamma \chi_{cJ}(1P) \rightarrow \gamma \gamma J/\psi(1S)$:
 - Serves as determination of $\text{BR}(\chi_{cJ}(1P) \rightarrow \gamma J/\psi(1S))$
- Inclusively measured $\text{BR}(\psi(2S) \rightarrow X J/\psi(1S))$:
 - $\sum_i \text{BR}(\psi(2S) \rightarrow X_i J/\psi(1S)) = \text{BR}(\psi(2S) \rightarrow X J/\psi(1S))_{\text{inclusive}}$ a powerful check on validity of the measurements
 - Test if “12% rule” satisfied with inclusive decays



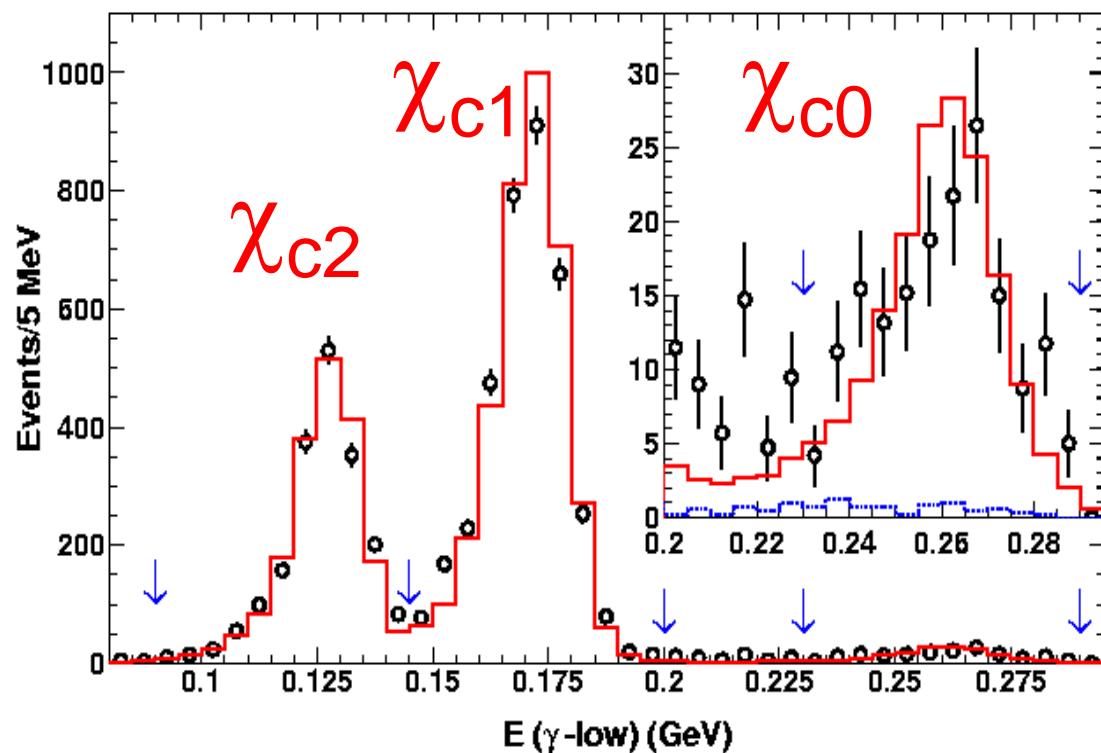
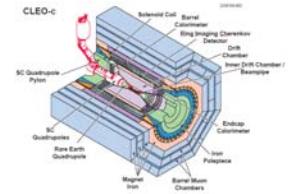
Inclusive BR($\psi(2S) \rightarrow X J/\psi(1S)$)



- Inclusive dilepton pairs:
Electrons and muons identified with loose E/p cuts

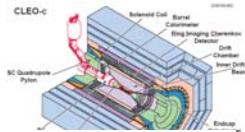
Exclusive

$\text{BR}(\psi(2\text{S}) \rightarrow \gamma\chi_{cJ}(1\text{P}) \rightarrow \gamma\gamma\text{J}/\psi(1\text{S}))$

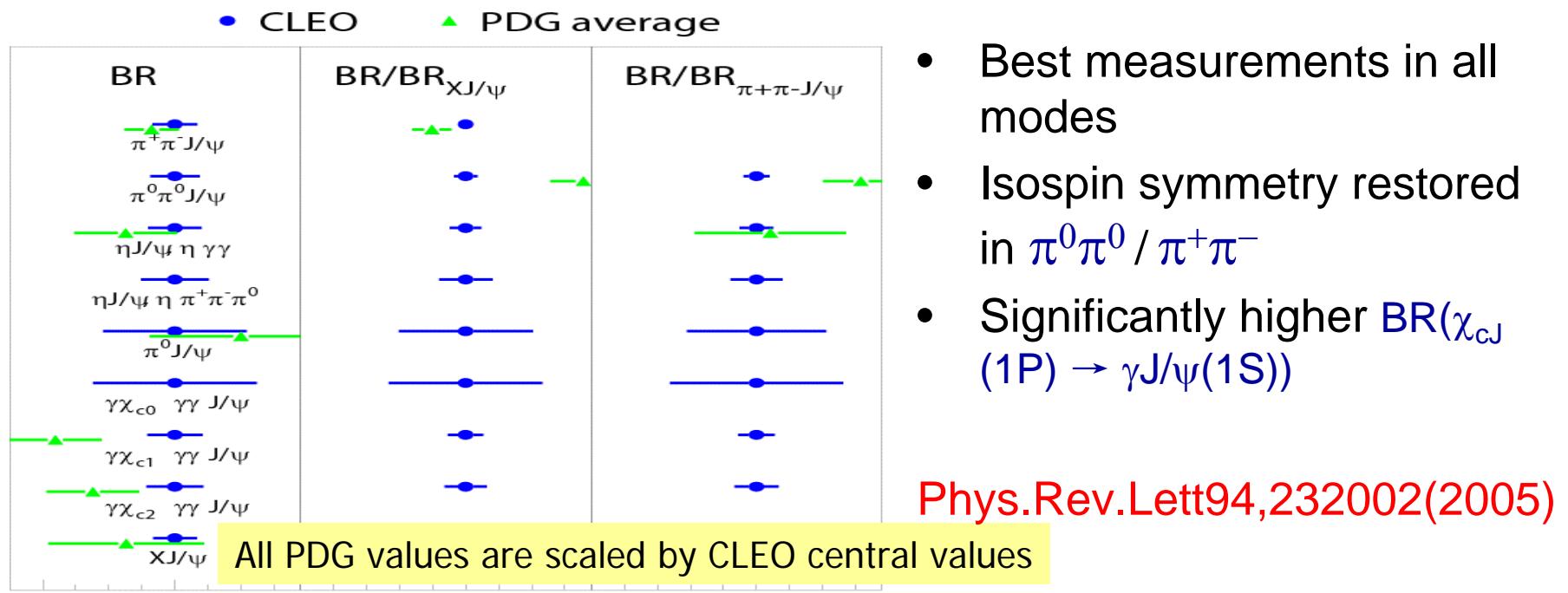


- Fully reconstructed events
- $\eta \rightarrow \gamma\gamma, \pi^0 \rightarrow \gamma\gamma$ suppressed by $250 < p(\text{J}/\psi) < 500 \text{ MeV}$, which corresponds to $227 < m(\gamma\gamma) < 522 \text{ MeV}$:
 - Other experiments used direct cuts on $m(\gamma\gamma)$ (*they really didn't have a choice*)
 - In CLEO-c resolution of $m(\gamma\gamma)$ calculated via $p(\text{J}/\psi \rightarrow \ell^+\ell^-)$ is actually better than calculated via $\gamma\gamma$

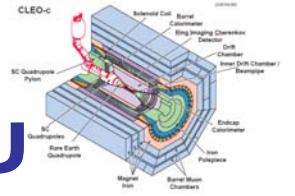
$\Psi(2S) \rightarrow XJ/\psi$ Results



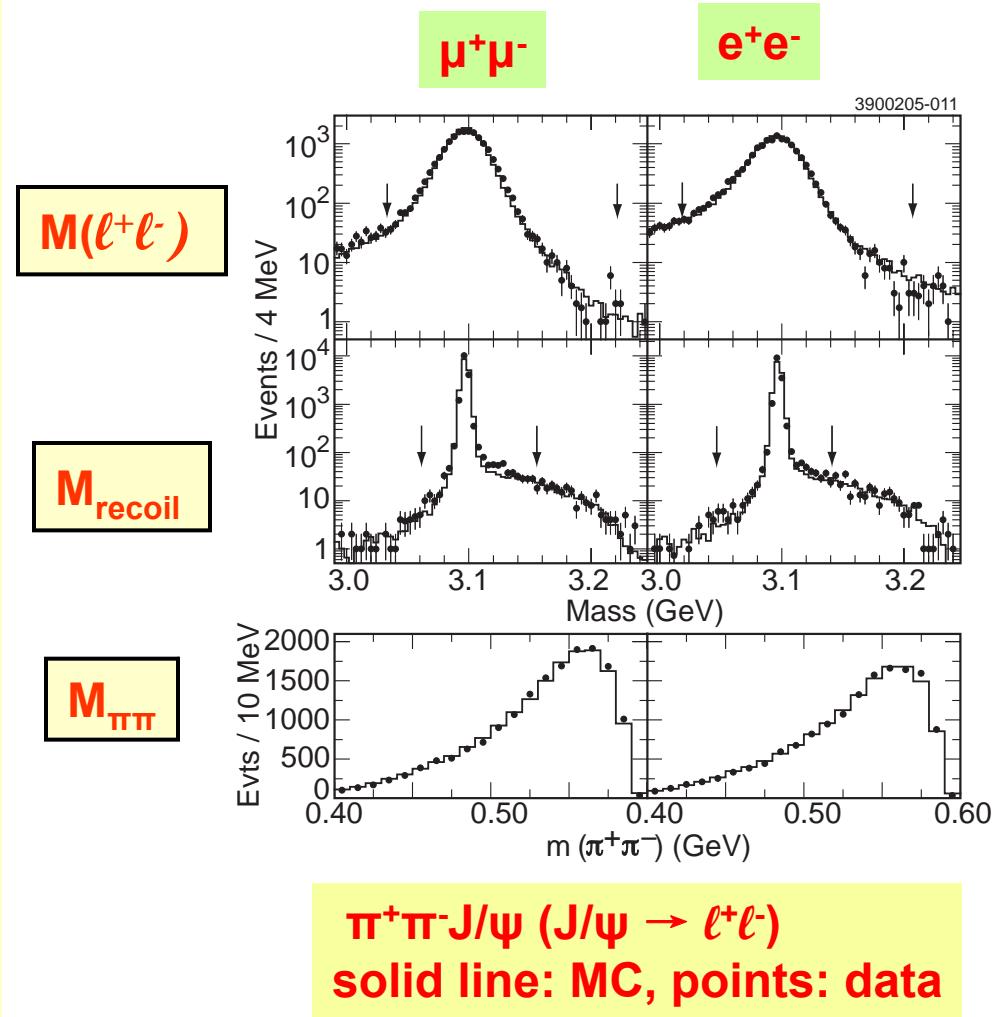
Channel	ϵ	$N_{\psi(2S)}$	N_{cont}	N_{bgd}	\mathcal{B}	$\mathcal{B}/\mathcal{B}_{XJ/\psi}$	$\mathcal{B}/\mathcal{B}_{\pi^+\pi^-J/\psi}$
$\pi^+\pi^-J/\psi$	49.3	60344	221	113	$33.66 \pm 0.14 \pm 1.10$	$56.37 \pm 0.27 \pm 0.46$	
$\pi^0\pi^0J/\psi$	22.2	13399	67	115	$16.58 \pm 0.14 \pm 0.58$	$27.76 \pm 0.25 \pm 0.43$	$49.24 \pm 0.47 \pm 0.86$
$\eta J/\psi$	22.7	2793	17	116	$3.24 \pm 0.06 \pm 0.12$	$5.45 \pm 0.10 \pm 0.06$	$9.66 \pm 0.19 \pm 0.15$
$\eta(\rightarrow\gamma\gamma)J/\psi$	16.9	2065	14	103	$3.22 \pm 0.07 \pm 0.11$	$5.39 \pm 0.12 \pm 0.06$	$9.56 \pm 0.21 \pm 0.14$
$\eta(\rightarrow\pi^+\pi^-\pi^0)J/\psi$	5.8	728	3	13	$3.40 \pm 0.13 \pm 0.13$	$5.70 \pm 0.21 \pm 0.13$	$10.10 \pm 0.38 \pm 0.22$
π^0J/ψ	13.9	88	3	20	$0.13 \pm 0.01 \pm 0.01$	$0.22 \pm 0.02 \pm 0.01$	$0.39 \pm 0.04 \pm 0.01$
$\gamma\chi_{c0} \rightarrow \gamma\gamma J/\psi$	23.4	172	20	17	$0.18 \pm 0.01 \pm 0.02$	$0.31 \pm 0.02 \pm 0.03$	$0.55 \pm 0.04 \pm 0.06$
$\gamma\chi_{c1} \rightarrow \gamma\gamma J/\psi$	30.6	3688	46	21	$3.45 \pm 0.06 \pm 0.13$	$5.77 \pm 0.10 \pm 0.12$	$10.24 \pm 0.17 \pm 0.23$
$\gamma\chi_{c2} \rightarrow \gamma\gamma J/\psi$	28.6	1915	56	62	$1.86 \pm 0.04 \pm 0.07$	$3.11 \pm 0.07 \pm 0.07$	$5.52 \pm 0.13 \pm 0.13$
XJ/ψ	65.3	151138	37916	123	$59.71 \pm 0.15 \pm 1.91$		

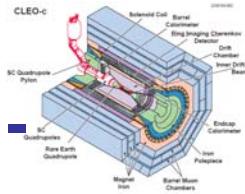


$B(J/\psi \rightarrow \ell^+ \ell^-)$ from $\Psi(2S) \rightarrow \pi^+ \pi^- J/\psi$



- Used in determination of $\Gamma_{\text{tot}}(J/\psi)$ and $\Gamma_{ee}(J/\psi)$ from $\sigma(e^+e^- \rightarrow J/\psi \rightarrow \text{hadrons})$
- Sensitive to the wave function at the origin: used to test potential models
- In this analysis we use $\Psi(2S) \rightarrow \pi^+ \pi^- J/\psi$ and measure $N(J/\psi \rightarrow \ell^+ \ell^-)$ & $N(J/\psi \rightarrow X)$ (determined from the inclusive $\pi^+ \pi^-$ recoil mass distribution).





Results for $J/\psi \rightarrow e^+e^-$ and $\mu^+\mu^-$

PRD 71, 111103(R) (2005)

$$B(J/\psi \rightarrow e^+e^-) = (5.945 \pm 0.067 \pm 0.042)\%, \text{ rel. } 1.3\%$$

$$B(J/\psi \rightarrow \mu^+\mu^-) = (5.960 \pm 0.065 \pm 0.050)\%, \text{ rel. } 1.4\%$$

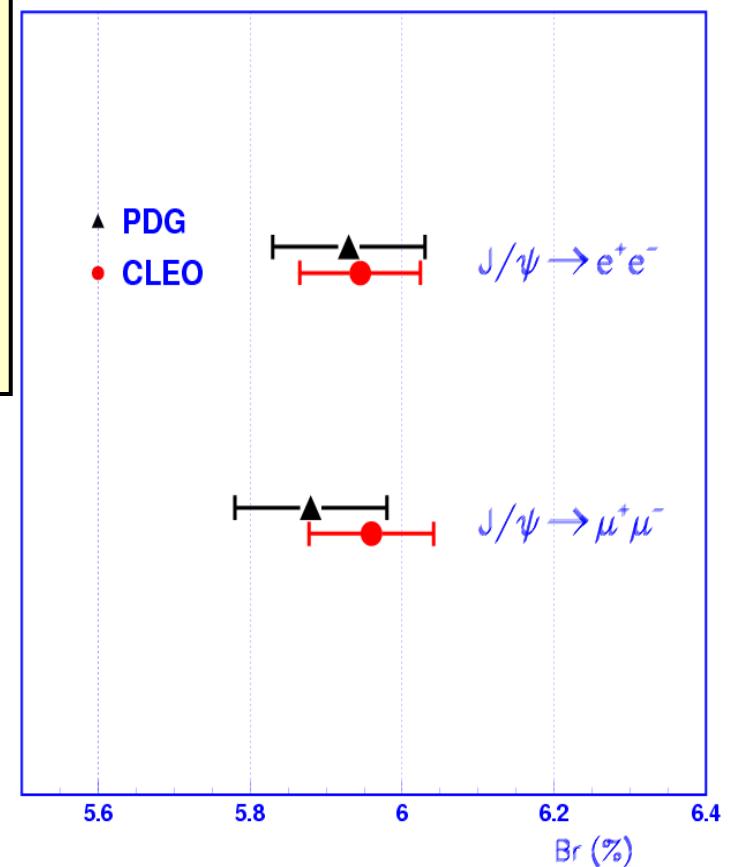
$$B(J/\psi \rightarrow \ell^+\ell^-) = (5.953 \pm 0.056 \pm 0.042)\%$$

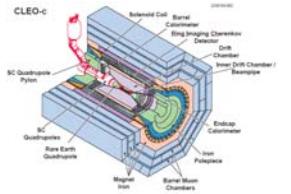
$$B(J/\psi \rightarrow e^+e^-)/B(J/\psi \rightarrow \mu^+\mu^-) = (99.7 \pm 1.2 \pm 0.6)\%$$

PDG

$$B(J/\psi \rightarrow e^+e^-) = (5.93 \pm 0.10)\%, \text{ rel. } 1.7\%$$

$$B(J/\psi \rightarrow \mu^+\mu^-) = (5.88 \pm 0.10)\%, \text{ rel. } 1.7\%$$





$\Psi(2S)$ to light hadrons

The branching fraction for $\psi(2S)$ decaying to light hadrons can be computed as the difference between unity and the branching fraction sum of all exclusive direct transitions measured in this work (and previous CLEO results).

That is: $1 - (\sum B[\psi(2S) \rightarrow J/\psi + h])$

- $(\psi(2S) \rightarrow \gamma \chi_{cJ}$ and $\psi(2S) \rightarrow \gamma \eta_c)$
- dilepton branching fractions

This yields

$$B[\psi(2S) \rightarrow \text{light hadrons}] = (16.9 \pm 2.6)\%.$$

To be compared with that of the J/ψ ,

$$B(J/\psi \rightarrow \text{light hadrons}) = (86.8 \pm 0.4)\%,$$

yielding a ratio of

$$(19.4 \pm 3.0)\%$$

which is $\sim 2.2\sigma$ above

$$B[\psi(2S) \rightarrow \ell^+ \ell^-] / B(J/\psi \rightarrow \ell^+ \ell^-) = (12.7 \pm 0.5)\%.$$

Hadronic decays of the $\Psi(2S)$

- $\Psi(2S)$: the “12% rule”?

For the charmonium system ($c\bar{c}$ annihilation),

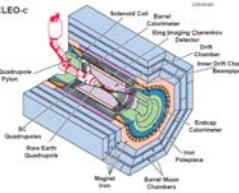
decay rate $\sim |\Psi(0)|^2$,

PDG04

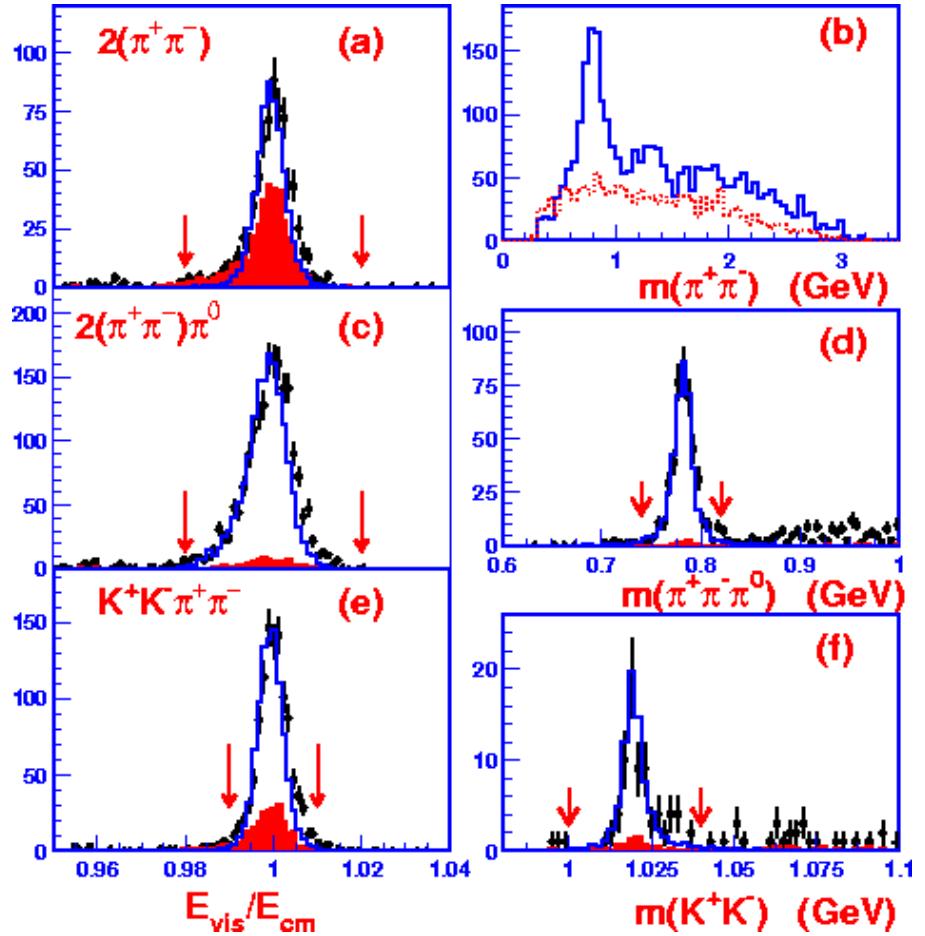
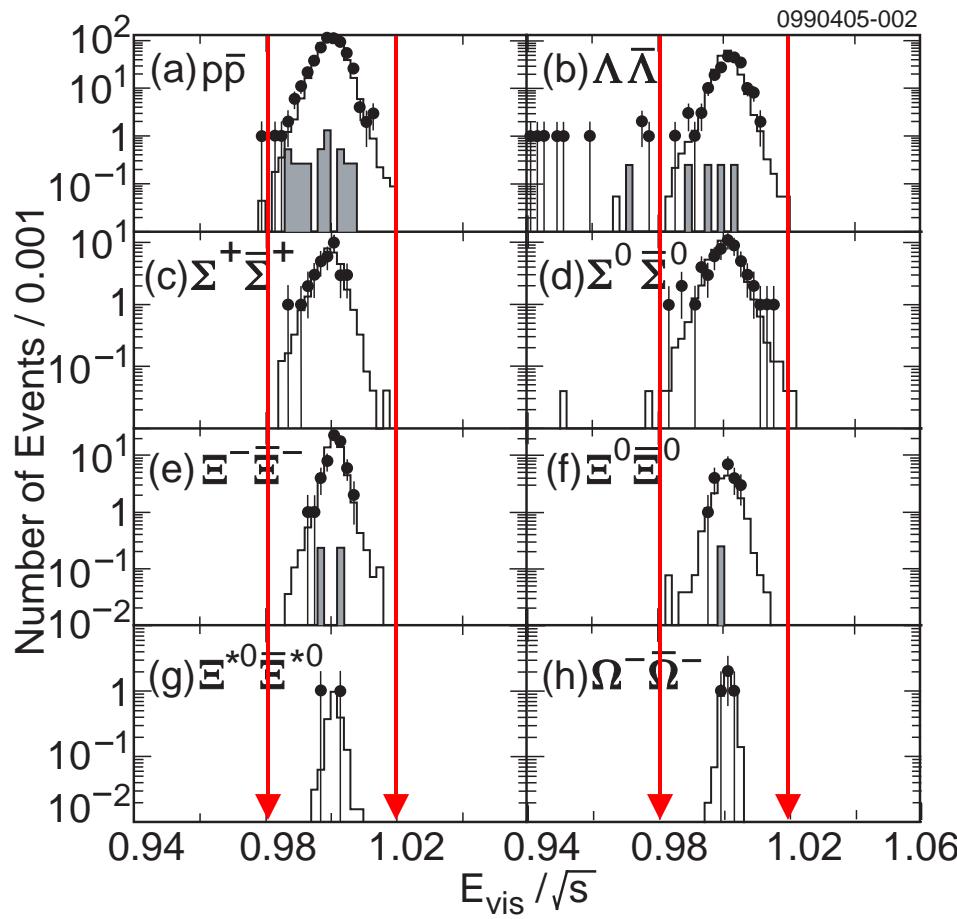
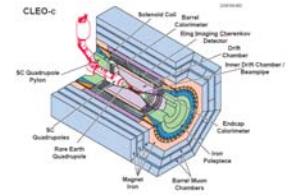


$$Q_h = \frac{B(\Psi(2S) \rightarrow h)}{B(J/\psi \rightarrow h)} = \frac{B(\Psi(2S) \rightarrow l^+l^-)}{B(J/\psi \rightarrow l^+l^-)} \approx (12.7 \pm 0.5)\%$$

- Information on resonant vs. non-resonant in multi-body final states.
- Hints for S-D mixing between $\Psi(2S)$ and $\Psi(3770)$.
- PID with combined RICH-dE/dx information;
- Scale continuum data for non-resonant subtraction;
- Use scaled energy and/or resonant mass to isolate signal.



Hadronic decays of the $\Psi(2S)$



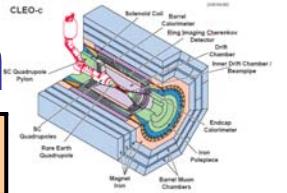
Scaled energy for baryon anti-baryon

Scaled energy and resonant production
in multi-particle hadronic decays

Results for $\Psi(2S) \rightarrow$ baryon anti-baryon

2 first observations

Phys. Rev. D 72, 051108(R) (2005)



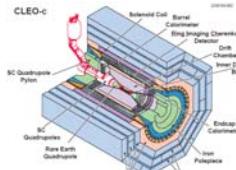
$$N_S = S_{\psi(2S)} - B_{\psi(2S)} - B_{cf} - f \bullet B_c, \quad Br = N_S / (\epsilon N_{\psi(2S)})$$

	Modes	$S_{\psi(2S)}$	$B_{\psi(2S)}$	$f_S \cdot B_c$	B_{xf}	ϵ	$\mathcal{Br}(10^{-4})$	Q(%)	$\sigma_{cont}(pb)$
$S=0$	$p\bar{p}$	557	0.5	4.06	0	66.6%	$2.87 \pm 0.12 \pm 0.15$	13.6 ± 1.1	$1.5 \pm 0.37 \pm 0.13$
-1	$\Lambda\bar{\Lambda}$	208	4.5	0.98	0	20.1%	$3.28 \pm 0.23 \pm 0.25$	25.2 ± 3.5	$1.12 \pm 0.56 \pm 0.11$
	$\star \Sigma^+ \bar{\Sigma}^+$	35	0.5	0.26	0.3	4.1%	$2.55 \pm 0.44 \pm 0.68$	-	$1.31 \pm 1.31 \pm 0.36$
	$\Sigma^0 \bar{\Sigma}^0$	58	0	0	0	7.2%	$2.63 \pm 0.35 \pm 0.21$	20.7 ± 4.2	-
-2	$\Xi^- \bar{\Xi}^-$	63	0	0.46	0	8.6%	$2.38 \pm 0.30 \pm 0.21$	13.2 ± 2.2	$1.20 \pm 0.85 \pm 0.13$
	$\star \Xi^0 \bar{\Xi}^0$	21	0	0.49	0	2.4%	$2.75 \pm 0.64 \pm 0.61$		$5.14 \pm 3.64 \pm 1.19$
	$\Xi^{*0} \bar{\Xi}^{*0}$	2	0	0	0	0.6%	$1.02 \pm 0.72 \pm 0.15$ (<2.2 @90 CL)	-	-
$J=3/2$	$\Omega^- \bar{\Omega}^-$	4	0	0	0	1.87%	$0.70 \pm 0.35 \pm 0.10$ (<1.3 @90 CL)	-	-

First observation

To be compared with (12.7 ± 0.5)%

Results for $\Psi(2S) \rightarrow$ multi-body



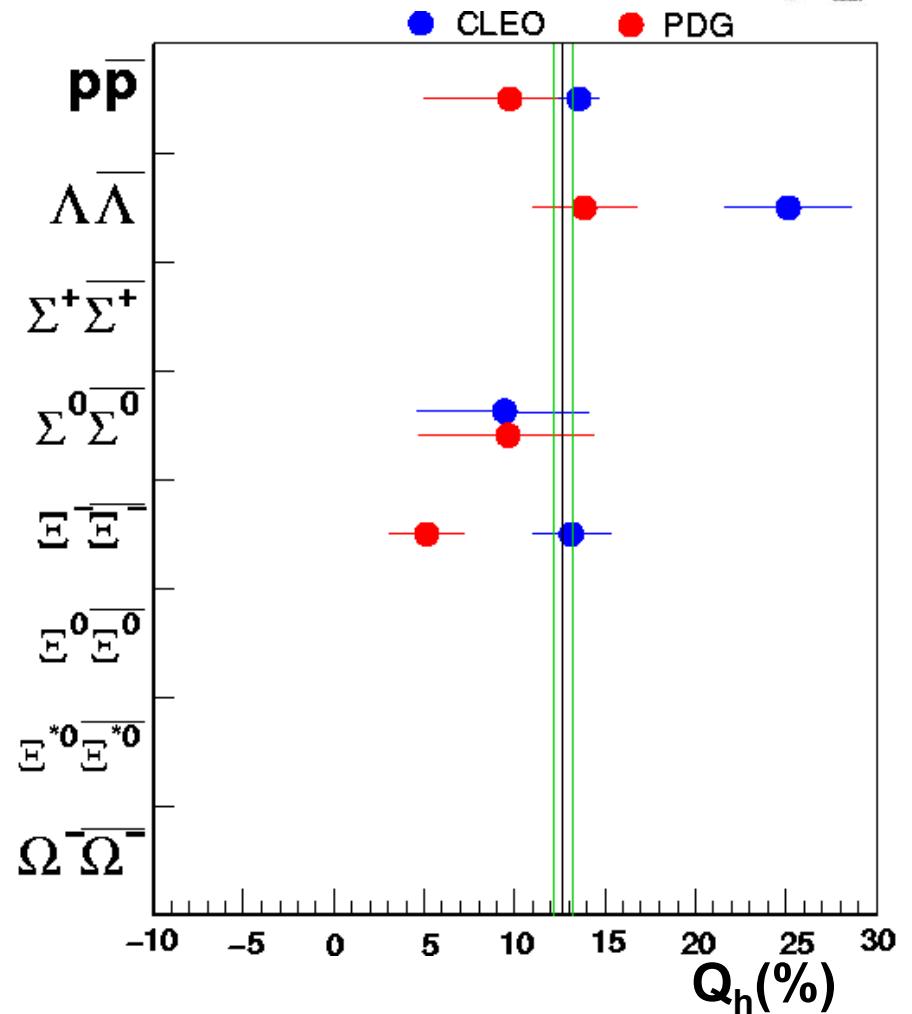
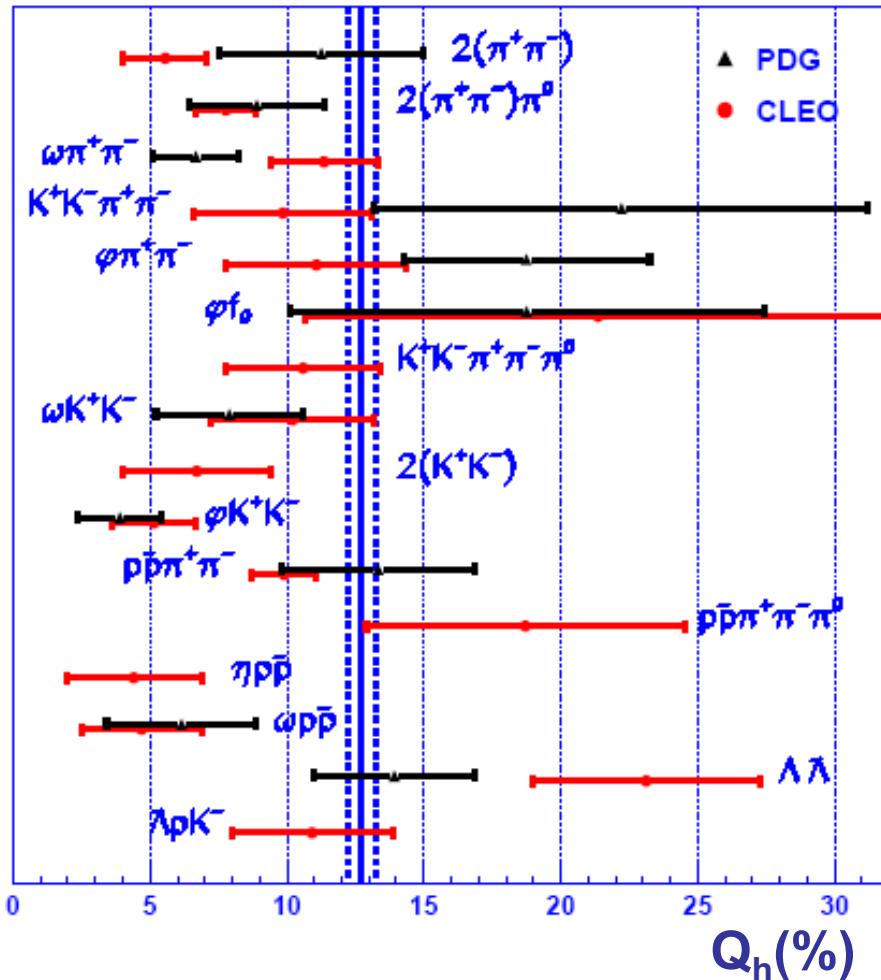
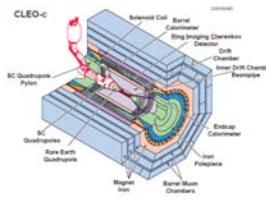
mode h	S_{co}	B_{co}	f	$S_{\psi(2S)}$	$B_{\psi(2S)}$	N_S	ε	$\mathcal{B}(\psi(2S) \rightarrow h)$ (10^{-4})	\mathcal{B} (PDG) (10^{-4})	Q_h (%)
$2(\pi^+\pi^-)$	1471	28	0.2668	713	20	308.0	0.4507	$2.2 \pm 0.2 \pm 0.2$	4.50 ± 1.00	5.55 ± 1.53
$\rho\pi^+\pi^-$	1168	-	0.2667	597	-	285.5	0.4679	$2.0 \pm 0.2 \pm 0.4$	4.20 ± 1.50	-
$2(\pi^+\pi^-)\pi^0$	352	25	0.2550	1825	39	1702.6	0.2115	$26.1 \pm 0.7 \pm 3.0$	30.00 ± 8.00	7.76 ± 1.10
$\eta\pi^+\pi^-$	15	0	0.2501	13	2	7.2	0.0416	< 1.6	-	-
$\omega\pi^+\pi^-$	43	9	0.2357	437	38	391.0	0.1553	$8.2 \pm 0.5 \pm 0.7$	4.80 ± 0.90	11.35 ± 1.94
$\eta 3\pi^a$	27	2	0.2513	243	35	201.7	0.0639	$10.3 \pm 0.8 \pm 1.4$	-	-
$\eta 3\pi^b$	20	9	0.1820	53	1	50.0	0.0199	$8.1 \pm 1.4 \pm 1.6$	-	-
$\eta 3\pi$								$9.5 \pm 0.7 \pm 1.5$	-	-
$\eta' 3\pi$	1	0	0.1721	17	4	12.8	0.0092	$4.5 \pm 1.6 \pm 1.3$	-	-
$K^+K^-\pi^+\pi^-$	871	83	0.2688	1072	43	817.2	0.3742	$7.1 \pm 0.3 \pm 0.4$	16.00 ± 4.00	9.85 ± 3.23
ρK^+K^-	170	-	0.2602	268	-	223.8	0.3361	$2.2 \pm 0.2 \pm 0.4$	-	-
$\phi\pi^+\pi^-$	33	13	0.2703	73	20	47.6	0.1744	$0.9 \pm 0.2 \pm 0.1$	1.50 ± 0.28	11.07 ± 3.30
$K^+K^-\pi^+\pi^-\pi^0$	634	18	0.2556	888	19	711.6	0.1818	$12.7 \pm 0.5 \pm 1.0$	-	10.59 ± 2.81
ηK^+K^-	3	0	0.2396	7	2	4.3	0.0354	< 1.3	-	-
ωK^+K^-	62	12	0.2435	97	8	76.8	0.1288	$1.9 \pm 0.3 \pm 0.3$	1.50 ± 0.40	10.19 ± 2.96
$2(K^+K^-)$	100	11	0.2669	85	2	59.2	0.3118	$0.6 \pm 0.1 \pm 0.1$	-	6.71 ± 2.74
ϕK^+K^-	46	15	0.2642	49	4	36.8	0.1511	$0.8 \pm 0.2 \pm 0.1$	0.60 ± 0.22	5.14 ± 1.53
$2(K^+K^-)\pi^0$	20	0	0.2675	51	1	44.7	0.1339	$1.1 \pm 0.2 \pm 0.2$	-	-
$p\bar{p}\pi^+\pi^-$	337	28	0.2509	1010	28	904.5	0.4943	$5.9 \pm 0.2 \pm 0.4$	8.00 ± 2.00	9.90 ± 1.16
$\rho p\bar{p}$	23	-	0.2570	67	-	61.1	0.4119	$0.5 \pm 0.1 \pm 0.2$	-	-
$p\bar{p}\pi^+\pi^-\pi^0$	204	9	0.2312	499	19	434.9	0.1921	$7.3 \pm 0.4 \pm 0.6$	-	18.70 ± 5.80
$\eta p\bar{p}$	2	1	0.2350	12	2	9.8	0.0399	$0.8 \pm 0.3 \pm 0.3$	-	3.80 ± 2.09
$\omega p\bar{p}$	26	4	0.2173	37	11	21.2	0.1129	$0.6 \pm 0.2 \pm 0.2$	0.80 ± 0.32	4.69 ± 2.22
$p\bar{p}K^+K^-$	25	1	0.2478	37	1	30.1	0.3671	$0.3 \pm 0.1 \pm 0.0$	-	-
$\phi p\bar{p}$	2	3	0.2631	6	2	4.3	0.1732	< 0.24	< 0.26	-
$\Lambda\bar{\Lambda}\pi^+\pi^-$	23	4	0.1902	91	14	73.4	0.0844	$2.8 \pm 0.4 \pm 0.5$	-	-
$\Lambda\bar{p}K^+$	65	7	0.2586	97	8	74.0	0.2472	$1.0 \pm 0.1 \pm 0.1$	-	10.92 ± 2.93
$\Lambda\bar{p}K^+\pi^+\pi^-$	29	3	0.1631	57	7	45.8	0.0847	$1.8 \pm 0.3 \pm 0.3$	-	-

13 first observations

Phys. Rev. Lett 95, 062001 (2005)

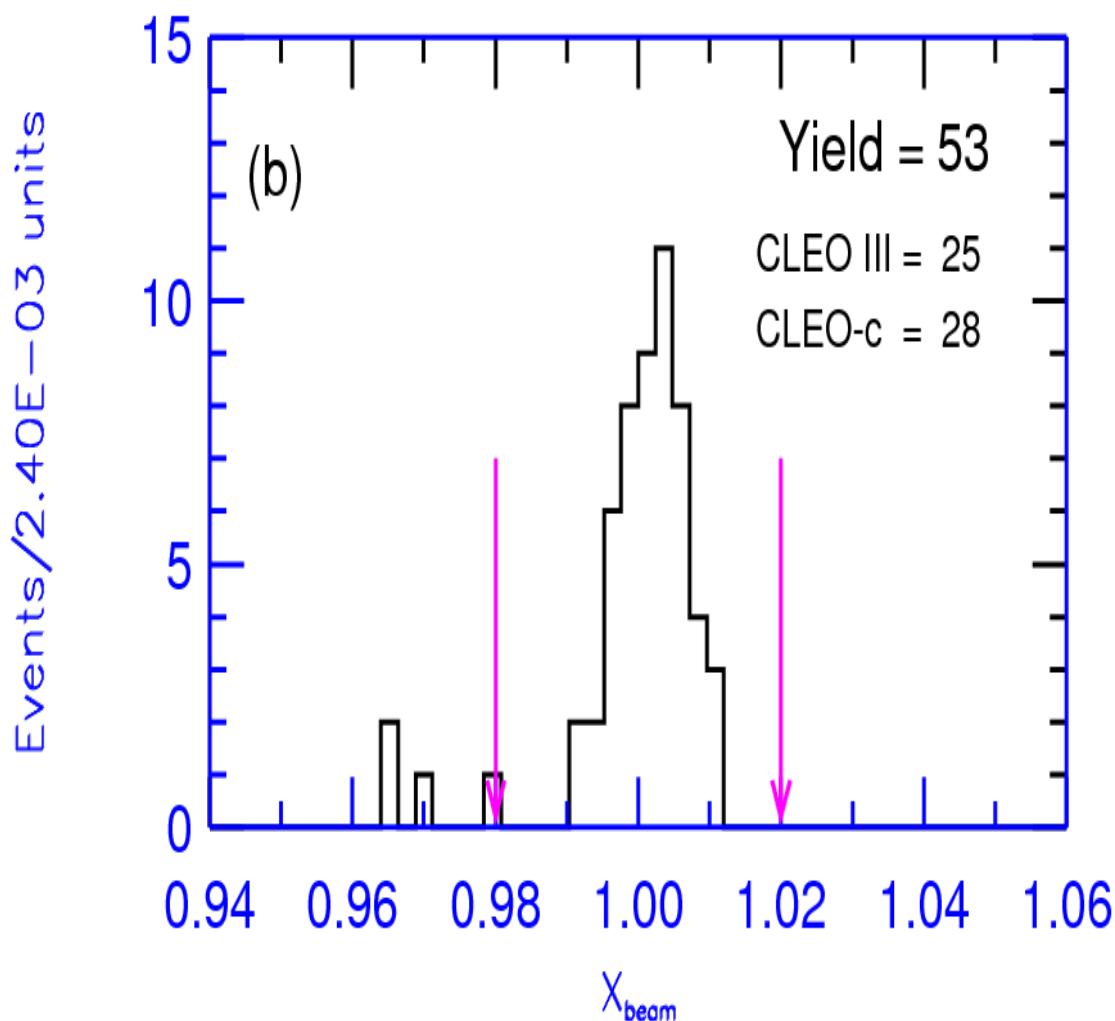
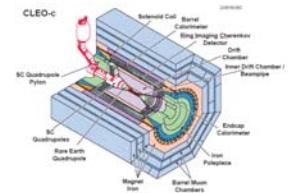
$12.7 \pm 0.5 ?$

The 12% rule: $Q_h = B(\psi(2S) \rightarrow h)/B(J/\psi \rightarrow h) \approx 12\%$



Reasonable agreement with the rule, in contrast to VP modes and $\pi^+\pi^-\pi^0$.

Measurement of $\mathcal{B}(\Psi(2S) \rightarrow K_S K_L)$



- Reconstruct $K_S \rightarrow \pi^+ \pi^-$
- DO NOT reconstruct K_L
- Allow possible K_L signature
- Veto π^0 ; veto γ outside K_L cone

Scaled energy of K_S :

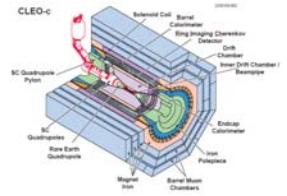
$$X_{beam} = E_{K_S} / E_{beam}$$

$$0.98 < X_{beam} < 1.02$$

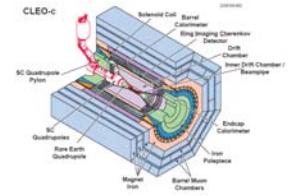
$$\mathcal{B}(\Psi' \rightarrow K_S K_L) = (5.84 \pm 0.80 \pm 0.43) \times 10^{-5} \quad \text{!!!CLEO PRELIMINARY!!!}$$

$$\mathcal{B}(\Psi' \rightarrow K_S K_L) = (5.24 \pm 0.47 \pm 0.48) \times 10^{-5} \quad \text{BES [PRL.92:052001,2004]}$$

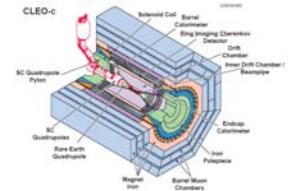
Summary



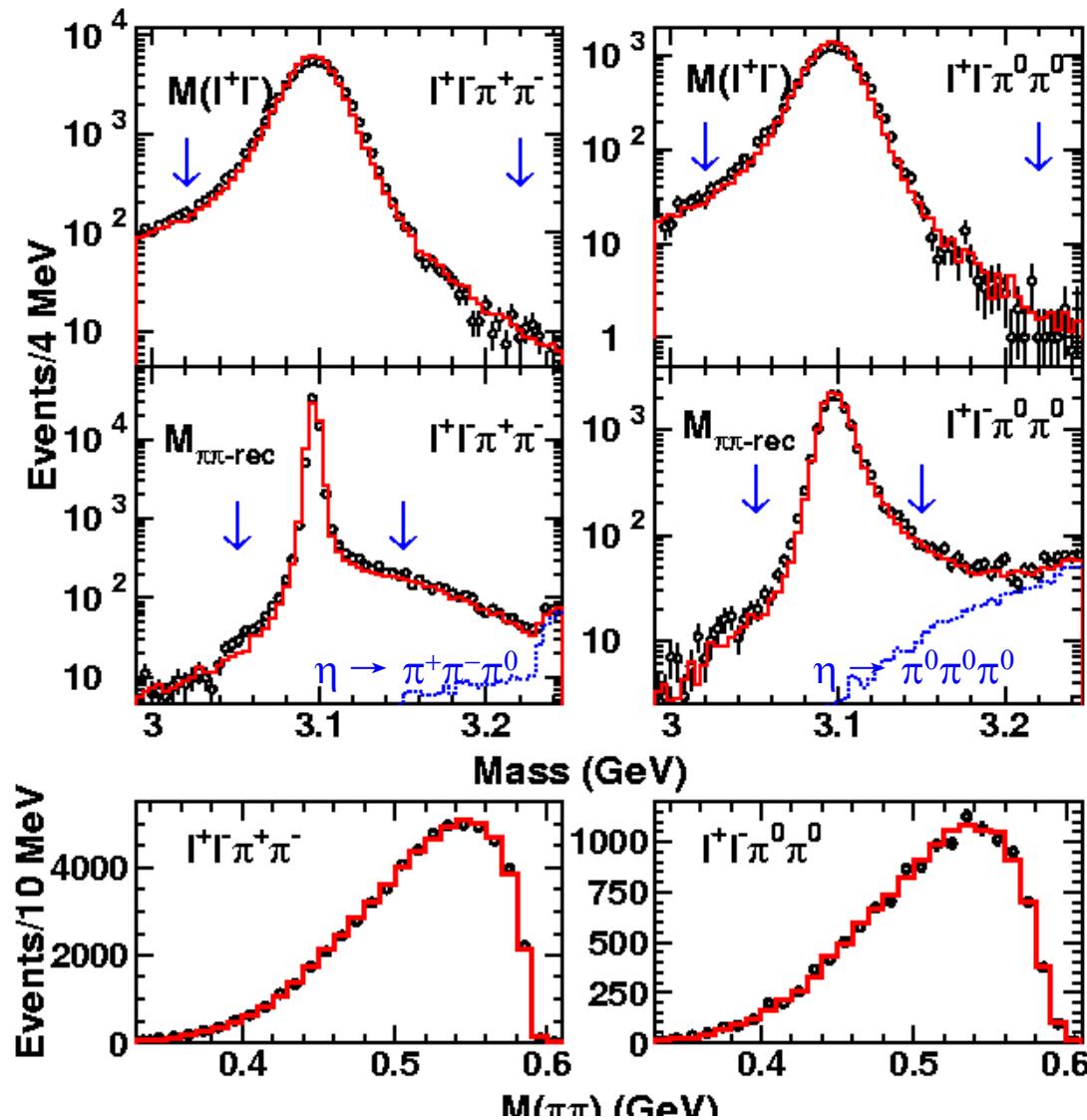
- ❖ CLEO-c has made a variety of measurements of charmonium transitions: $\Psi(2S) \rightarrow XJ/\psi$, $J/\psi \rightarrow \ell^+ \ell^-$, $\Psi(2S) \rightarrow$ baryon pair, $\Psi(2S) \rightarrow$ multi-body hadrons and $\Psi(2S) \rightarrow K_S K_L$.
- ❖ The results presented are part of a continuing detailed systematic analysis of charmonium decays by the CLEO collaboration. Most of the results are either first observations or of higher precision than previous measurements.
- ❖ CLEO-c plans to continue running for the next few years in the charm region both for the bound states and for open charm meson production.



Backup slides

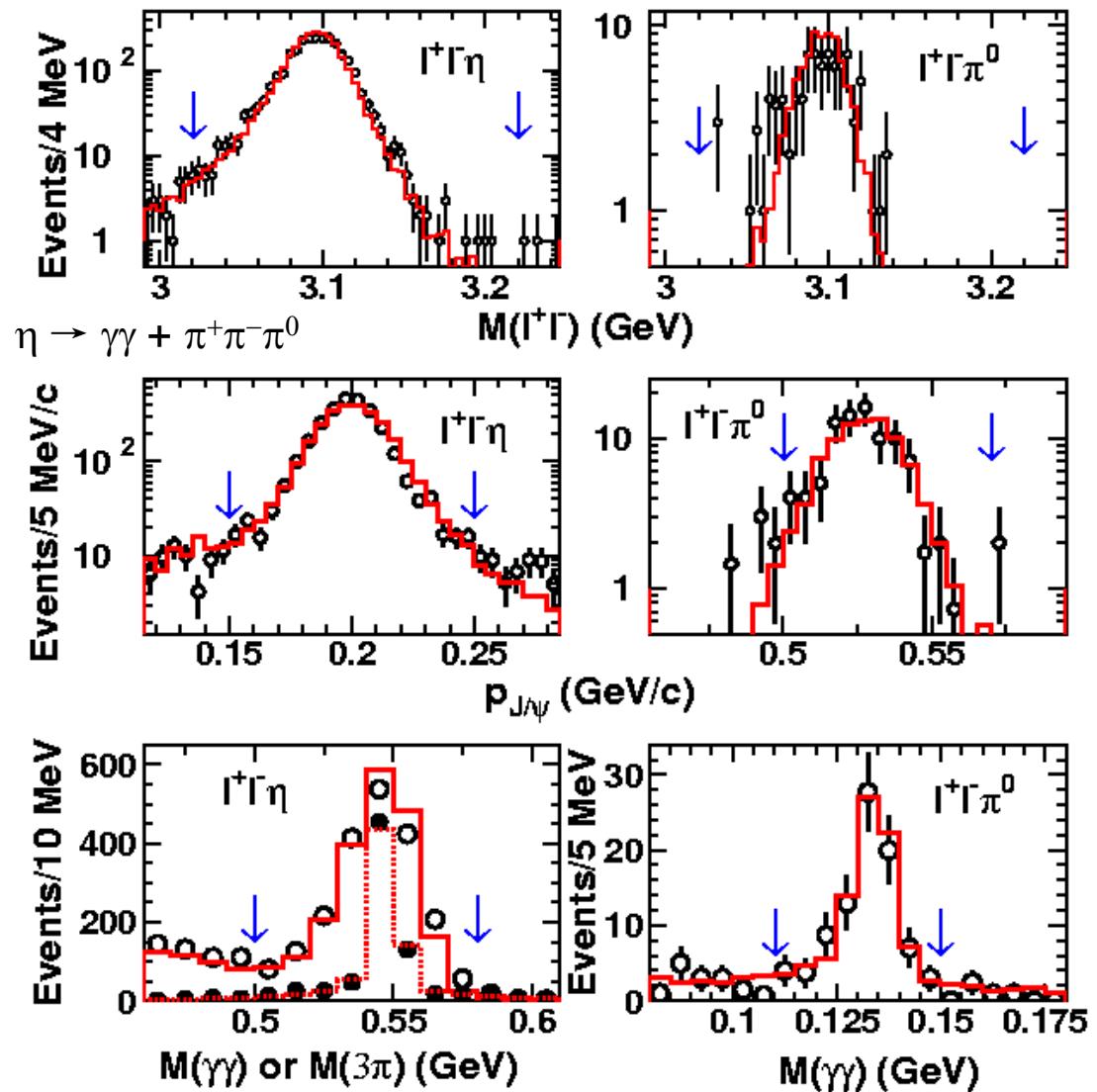
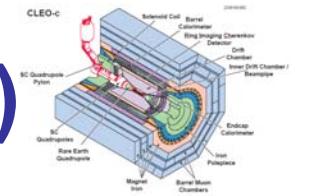


Exclusive BR($\psi(2S) \rightarrow \pi\pi J/\psi(1S)$)

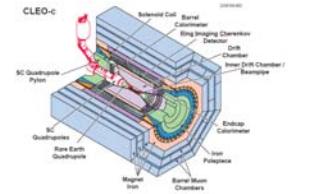


- Fully reconstructed events:
 - Energy-momentum conservation
 - Dilepton mass and dipion-recoil mass consistent with J/ψ

Exclusive BR($\psi(2S) \rightarrow \eta, \pi^0$ J/ $\psi(1S)$)



- Fully reconstructed events
- $\eta \rightarrow \gamma\gamma$ and $\pi^+\pi^-\pi^0$
- $\pi^0 \rightarrow \gamma\gamma$



$N_{\pi^+\pi^- \text{ J}/\psi, \text{ J}/\psi \rightarrow X}$: Fitting Recoil Mass Spectrum

- $\pi^+\pi^- (\text{J}/\psi \rightarrow X)$:
 - $p_T > 150 \text{ MeV}/c$, $|\cos\theta| < 0.83$,
 - $m(\pi^+\pi^-) = 400\text{-}600 \text{ MeV}$
 - Fit $M(\pi^+\pi^- \text{-recoil})$ for N_X
- $M(\pi^+\pi^- \text{-recoil})$ uses only the pions, hence \sim independent of what the J/ψ does.
- Efficiency is obtained by weighting a set of basis modes to produce $\text{J}/\psi \rightarrow X$ mix.

